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Thesis

The Oscillation Valve in the Transmission and Reception of Radio Messages

Submitted by

Edwin Carey Kennedy

(S.B., Tufts, 1921)

In partial fulfillment of requirements for the degree of Master of Arts.

1922

- OUTLINE OF THESIS -

"THE OSCILLATION VALVE IN THE TRANSMISSION AND RECEPTION OF RADIO MESSAGES".

(A) Introduction:- Important distinctions in radio transmission and reception.
- (1) Audio and Radio Frequency Currents.
- (2) Damped and Undamped Oscillations.
- (3) Receiver Circuits.
  - (a) Open and Closed.
  - (b) Necessity for Tuning.

(B) History of the Oscillation Valve.

(C) Operating Principles of the Valve.
- (1) The Electron Theory.
- (2) Rectifying Properties.
- (3) Unilateral Conductivity.
- (4) "Saturation".
- (5) Two Electrode Valve.
- (6) Three Electrode Valve.

(D) Practical Applications of the Valve.
- (1) The Three Electrode Valve as a Rectifier.
- (2) The Three Electrode Valve as a Relay.

(E) Cascade Amplification by the Valve.
- (1) Radio Frequency.
- (2) Audio Frequency.
- (3) Combined Radio and Audio Frequency.

(F) The Regenerative Vacuum Valve Amplifier.

(G) The Vacuum Tube as a Continuous Wave Detector.
- (1) Beat Reception.
  - (a) Heterodyne Action.
  - (b) Autodyne Action.

(H) The Vacuum Tube in Radio Telephony.
- (1) As a Generator of Undamped Oscillations.
- (2) As a Modulator

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THE OSCILLATION VALVE IN THE TRANSMISSION AND RECEPTION OF RADIO MESSAGES

The predominating factor in the marvelous advance of radio telegraphy and telephony during the past few years has been the oscillation valve. Without this wonderful device, so young in years, yet so old in its training and broad usefulness, many of our present radio achievements would not exist. The oscillation valve (often called by such terms as "vacuum valve", "electron tube", "vacuum tube", and also by trade names such as "audion", "audiotron", etc.) finds many applications in the electrical industry, but certainly none so useful as in radio work, where it plays important roles in both transmission and receiving of radio telegraphy and telephony. One fact of importance is that such tubes make possible the use of apparatus that is easily portable - a primary consideration in military communication, and of importance also in various commercial application. The principles which underlie the operation of electron tubes and their action under the widely different conditions met in actual practice therefore deserve careful study.

Before beginning an explanation of the functioning of the vacuum tube, a brief review of certain facts bearing on wireless transmitting and receiving systems will be given.

AUDIO AND RADIO FREQUENCY CURRENTS

Vibrations above 20,000 per second are practically inaudible to the human ear. This fact is very important in regard to the reception of radio signals by means of a telephone receiver. For instance, if an electric current with a frequency of 20,000 cycles per second flows through the windings of a telephone the diaphragm will vibrate 20,000 times per second. As has been stated, this frequency approaches the upper limit of audibility. Now if this frequency is progressively decreased the vibrations of the diaphragm become more and more audible until some value is reached where the maximum deflection of the diaphragm is secured for a given E. M. F.

Taking the above into consideration, a figure of 10,000 cycles has been arbitrarily adopted as the upper limit for currents of audio frequency. Currents of frequency above 10,000 cycles per second are termed currents of radio frequency.①

①- "Vacuum Tubes in Wireless Communication": Bucher- page 1.

THE OSCILLATION VALVE IN THE TRANSMISSION AND RECEPTION OF RADIO MESSAGES

The electric waves for the dispatch of wireless messages are ordinarily generated by extremely high frequency currents of 500,000 to 1,000,000 cycles per second (for ship to ship and ship to shore messages.) For long distance messages, such as transatlantic transmission, much lower frequencies of the order of 20,000 to 100,000 cycles per second are used. Currents of similar frequency are induced in the receiver circuits. But in all cases the frequencies are above the range of audition, thus it is clear that the telephone receiver cannot be employed as an indicator for currents of these frequencies.

An audio frequency current of from 200 to 1000 impulses per second gives audible response with a minimum of current, and, as the telephone receiver is almost invariably employed as a current translator in radio, the problem resolves itself into one of converting radio frequency currents into audio frequency currents such as will give the best response in a telephone.

DAMPED AND UNDAMPED OSCILLATIONS

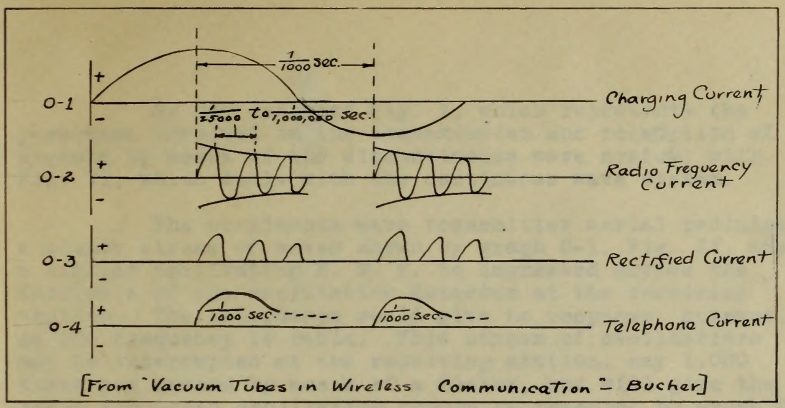
There are two general systems in use in radio communication: - the discontinuous wave system, and the continuous wave system. The currents which are set in motion by these waves are called damped and undamped oscillations respectively. In the discontinuous system the radio frequency currents are generated in audio frequency groups of 120 to 1,000 per second. Such currents are obtained by the charge and discharge of a condenser through a circuit containing an inductance. A spark coil is ordinarily used to alternately charge and discharge the condenser.

Continuous oscillations may be generated in four ways, by means of:-

(1) The radio frequency alternator
(2) The direct current arc generator
(3) The vacuum tube oscillator
(4) Overlapping trains of damped oscillations.

The principal points of difference between the damped and undamped wave systems, and particularly the problems involved in the detection of currents in either system, with which this Thesis is more deeply concerned, may be explained graphically by means of curves, as given in Bucher's "Vacuum Tubes in Wireless Communication".

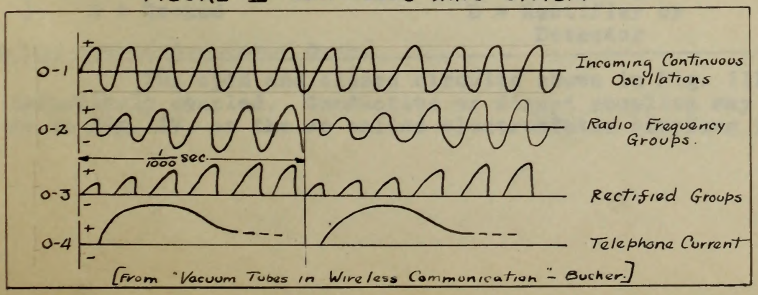
FIGURE I- DISCONTINUOUS WAVE SYSTEM.



In the above figure graph 0-1 indicates one cycle of charging current impressed across the transmitter condenser (by a high voltage transformer, e.g.) Assuming the condenser to be charged twice for each cycle, the frequency of the current is 500 cycles per second. The discharge of the condenser across the spark gap will give rise to radio frequency currents. Each alternation of the charging current, therefore, releases in the closed oscillation circuit one group of radio frequency oscillations, which are in turn induced in the antenna circuit by means of a coupling coil, and giving the oscillations shown by graph 0-2.

At the receiving station currents of similar frequency are induced in the receiving apparatus, but as these frequencies are above audibility no direct response is heard in the telephone receiver. If, however, a rectifier, such as a crystal of carborundum, galena, silicon, etc., in the form of a detector, or a vacuum tube giving one way conductivity, is connected in the circuit, these currents will be converted into a series of semi-cycles as in graph 0-3. No response will be obtained in the telephone from the individual impulses, as they are still at radio frequency, but since they all flow in one direction the telephone diaphragm responds to the average affect, as shown in graph 0-4.

FIGURE II- CONTINUOUS WAVE SYSTEM.



We may contrast Fig. I, which represents the phenomena involved in the transmission and reception of signals by means of the discontinuous wave system, with Fig. II, which deals with the continuous wave system.

The continuous wave transmitter aerial radiates a steady stream of waves shown by graph 0-1, Fig. II, and a similar oscillating E. M. F. is impressed across the terminals of the oscillation detector at the receiving station. The telephones would give no response, however, as the frequency is radio. This stream of oscillations may be interrupted at the receiving station, say 1,000 times per second by means of a ticker, and will give the radio frequency oscillation groups represented by graph 0-2. Rectification of these groups is represented in graph 0-3, and the resulting telephone current by graph 0-4.

RECEIVER CIRCUITS

Ordinarily the modern receiving set consists of an open primary circuit, and a closed, or secondary circuit.

A representative circuit is shown in Figure III.

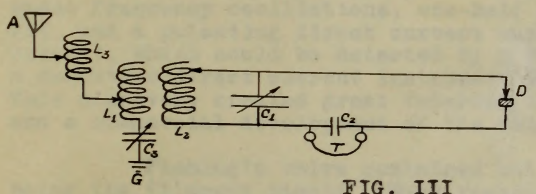


FIG. III

Open Circuit	A = Aerial	L-2 = Secondary of Receiving Transformer	Closed Circuit
	L-3 = Loading Inductance	C-1 = Variable Condenser	
	L-1 = Primary Receiving Transformer	C-2 = Shunt Condenser	
	C-3 = Short wave Condenser	T = Telephones	
	G = Ground	D = Rectifier or Detector	

[From "Vacuum Tubes in Wireless Communication" - Bucher.]

The open and closed circuits shown in Fig. III are inductively coupled. Conductive or direct coupling may be used as in Fig. IV, or the so called electrostatic coupling in Fig. V.

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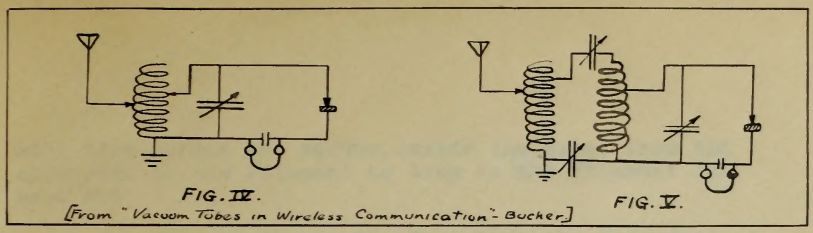


FIG. IV.
[From "Vacuum Tubes in Wireless Communication"- Bucher]

FIG. V.

Thousands of variations of the above three fundamental types of circuits are in use.

The open and closed oscillation circuits (or the antenna and detector circuits) must be tuned to close resonance in any two circuit receiving system, in order to get the maximum value of the oscillating E. M. F. which is impressed across the terminals of the detector. The use of crystal rectifiers does not require such care and precision in tuning as some of the vacuum tube circuits to be described later.

HISTORY OF THE OSCILLATION VALVE

Dr. J. A. Fleming of London was the first to employ the emmission of electrons from heated metals, to rectify or detect radio frequency oscillations in a wireless telegraph receiving system. He called his product a glow lamp oscillation detector, or oscillation valve. He adopted the latter name, because he found that the lamp would conduct electricity better in one direction than in the opposite.

Thus, if the valve was connected to a source of radio frequency oscillations, one-half of each cycle was cut off, and a pulsating direct current made to flow in the circuit, which could be detected by a telephone receiver, or a sensitive direct current instrument such as the galvanometer. This discovery created great interest in the scientific world, and a commercial development of the valve began soon afterwards.

Fleming's valve contained but two electrodes, one being the filament itself. Many regard the later development of the valve by Dr. Lee DeForest as of still greater importance. DeForest added a third element called the grid, to the valve, which improved it enormously, making possible a much wider range of circuits and greater ease of control.

OPERATING PRINCIPLES OF THE VALVE

The action of the oscillation valve is due to the very small particles of matter called electrons.(1) If two wires are connected to a battery, one to each terminal, the other two ends of the wires may be brought very close together in air, yet so long as they do not touch, no current flows. Or the two ends may be inclosed in a bulb like an electric lamp, but so long as they do not touch, no current flows between them. However, if a second metallic element be introduced into an electric lamp, insulated from the filament wires and maintained at a voltage positive to the filament, a current

(1) For further information on the nature of the electron, consult "The Electron" by R.A. Millikan. (1917)

will flow across the vacuum, inside the tube, from the electrode to the filament as long as the filament is kept hot.

This is due to the fact that the incandescent filament shoots off electrons at high velocity, each carrying a charge of negative electricity, and these electrons are attracted to the positive electrode. The passage to the second wire of the negative charge of the electrons is equivalent to the flow of a current between the filament and second wire. It should be noted that while the electrons move from the heated filament to the cold second wire, the current passes from the second wire to the filament, according to the usual idea that the direction of an electric current is from the positive (higher) to the negative (lower) voltage. This distinction between the direction of electron flow and the direction of current flow should be kept in mind.

As each electron leaves the filament, the filament acquires a charge of positive electricity equal in amount to the negative charge carried by the electron. If no voltage is applied to the second wire, electrons will still be emitted by the incandescent filament, but will travel only a very short distance before being attracted back to the filament by the positive charge acquired by the filament. The positive voltage applied to the second wire must be sufficient to overcome this attraction of the filament. If the second wire is connected with the negative pole of a battery, no current will flow in the tube, because the electrons will be repelled back into the filament by the negative charge on the second wire.

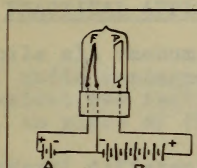
A tube which contains only the filament and one additional wire is called a two-electrode valve, the filament being considered as one electrode. The additional wire is generally in the form of a plate, and various shapes of plates are used in the different tubes. The current which flows between the filament and plate is known as the plate current.

As stated before, the oscillation valve may act as a rectifier of alternating currents of extremely high frequencies. For this reason it is said to possess "unilateral conductivity", meaning, of course, that it will conduct electricity in one direction only. This property will be taken up in detail later in this paper.

The strength of the current flowing between filament and plate is limited in two ways. First, by the temperature

limitation of the filament, and second by the so-called space charge. The amount of current passing per second from plate to filament varies directly with the supply of electrons. Thus the first limitation expressed above can be readily comprehended. For a given filament temperature, a certain number of electrons are emitted per second, and only the equivalent current of this supply of electrons can flow regardless of how much the positive charge on the plate is increased.

Figure VI shows the essential elements and connections of a two-electrode tube.



F = Filament
P = Plate
A = Battery for heating filament.
B = Battery for sending current through space and filament.

From "The Principles Underlying Radio Communication" — Signal Corps, U.S.A.

FIG. VI.

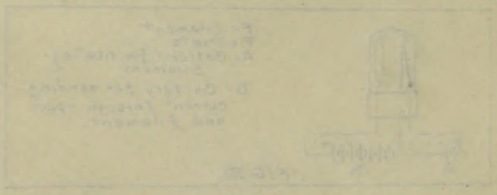
The second limitation expressed above, that of the space charge, may be explained as follows: For a given voltage applied to the plate, as the filament temperature is steadily increased, the number of electrons emitted will also increase. A point is finally reached where the electric field intensity, due to the presence of the negative electrons in the space between filament and plate, equals and neutralizes that due to the positive potential of the plate. A further increase in filament temperature is now unable to cause an increase in plate current, because for any extra electrons emitted from the filament an equal number of those in the space are repelled back into the filament.①

THE THREE ELECTRODE VALVE

A third electrode may be inserted between the filament and plate, as the form of a metallic gauge or grid of fine wires is generally called the "grid". "The addition of this third electrode makes it possible to increase of decrease the current between plate and filament through wide limits. If a voltage is applied to thegrid by means of a third battery connected between the filament and the grid, the space charge effect can be modified. The electrons traveling from filament to plate must pass through the grid."②Therefore by varying the potential of the grid between positive and negative, we can either retard or

①- "Vacuum Tubes in Wireless Communication"- Bucher [pp 26-28]

②- "The Principles Underlying Radio Communication" Signal Corps, U.S.A. [page 458]



speed up the progress of these electrons. By making the grid increasingly negative a point is reached where no flow of electrons will take place between filament and plate.

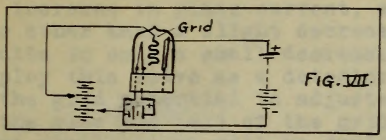


FIG. VII.

From "The Principles Underlying Radio Communication" — Signal Corps, U.S.A.

Fig. VII shows the two electrode circuit of Fig. VI with grid and grid battery added.

PRACTICAL APPLICATIONS OF THE VALVE

While all vacuum valves used at present for the reception of radio messages are of the three electrode type, the old two-electrode rectifier may be used in a circuit such as Fig. III, in place of the crystal rectifier D.

Several different groups of curves may be plotted for the three-electrode valve from which its operating characteristics may be readily seen.

Thus the plate voltage may be plotted against the plate current, giving curves dependent upon the temperature of the filament, or the grid voltage may be plotted against the grid current. The most satisfactory curve, and the one most commonly used for explaining the operation of the tube is the grid-voltage, plate current curve, shown in Fig. VIII.

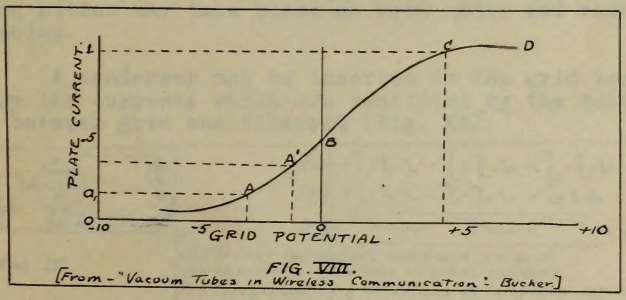


FIG. VIII.

[From - "Vacuum Tubes in Wireless Communication" Bucher]

The voltage of the plate battery was kept constant while the grid battery was varied at positive and negative potentials. The above curve is important, because the explanations at present accepted, as regards the fundamental actions of the three-electrode vacuum valve as a detector and amplifier in radio, are based on the operating characteristics shown in the curve.

Fig. VII shows the two electrode circuit of Fig. VI with grid and grid battery added.

Supposing (in Fig. VIII) the grid potential has been adjusted to — 3 volts (represented by "A" on the diagram). Now a slight increase in grid potential will cause a large increase in plate current, as shown by the curve. On the other hand a slight decrease in grid potential results in only a small decrease in plate current. Thus if we employ this valve as a detector in a receiving circuit, and the grid potential is adjusted to point A, (Fig. VIII), the rise and fall of the grid potential due to the incoming oscillations will be duplicated in the plate circuit, with the exception that the amplitudes of the increase exceed those of the decrease. This results in what amounts to a uni-directional current in the telephone receiver.

The above is shown graphically in Fig. X. Fig. IX is the ordinary circuit employing the vacuum tube as a detector or rectifier.

RELAYING ACTION OF THE THREE-ELECTRODE VALVE

The grid circuit of a valve is generally referred to as the "input" circuit, and the plate circuit the "output" circuit.

It has been shown from the characteristic curve in Fig. VIII that the valve acts as a relay; a current of any form impressed on the grid circuit can be repeated with amplification in the plate or output circuit. It is because of the extreme mobility of electrons that this relaying action may take place at both audio and radio frequencies.

A condenser may be inserted in the grid lead to store up the currents which are rectified by the valve action between grid and filament (Fig. XI).

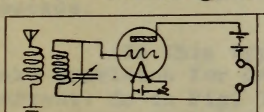


FIG. IX.

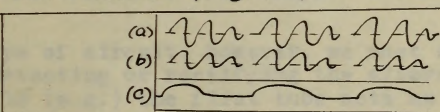


FIG. X.

(a) Voltage oscillations impressed on grid.
(b) Resulting variations in plate current
(c) Corresponding fluctuations of telephone current.

From "The Principles Underlying Radio Communication." — Signal Corps, U.S.A.

During the time that the rectified oscillations are building up a charge in the grid condenser, the current in the plate circuit decreases, but when the charge leaks out of the condenser, the plate current returns to normal value. This should happen before the next wave train comes

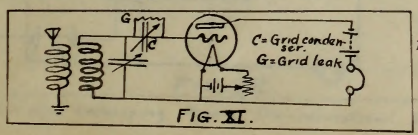


FIG. XI.

From "The Principles Underlying Radio Communication." — Signal Corps, U.S.A.

along, and in order to insure this a resistance of a megohm may be shunted across the condenser. This resistance is called a "grid leak".

The "repeated" current in the plate circuit referred to above is of radio frequency and is therefore not heard in the telephone, the latter instrument indicating only the rectified current flowing from plate to filament. The repeated radio frequency current is utilized, however, in the regenerative and amplification circuits to be discussed later.

The terms "audio-frequency component of the plate current" and "radio frequency component of the plate current" are given to the charge which accumulates in the grid condenser during a group of incoming oscillations, and the repeated radio frequency current respectively. (1)

To sum up the relaying and rectifying properties of the oscillation valve discussed above, it may be said that while the tube is acting as a detector (rectifier) it is also acting as an amplifier - that is, oscillations of greater power are produced in the plate circuit for a given alternating voltage in the grid circuit than would be produced if the same voltage were applied directly to the plate circuit.

CASCADE AMPLIFICATION BY THE VACUUM VALVE

It has been shown that a single valve will exert an amplifying action on the incoming oscillations. That is, the output (plate) circuit current is amplified in respect to the input (grid) circuit current. Now if we connect the output circuit of one valve to the input circuit of a second valve, and so on, still greater amplification will result. In this kind of circuit the valves are said to operate in cascade.

In this type of circuit, however, we must still make provision for detecting or rectifying the alternating current. So in Fig. 12 (e.g.) the first tube acts as an amplifier and the second as a detector.

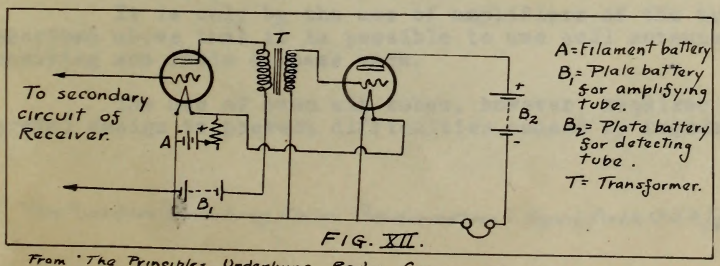


FIG. XII.

From "The Principles Underlying Radio Communication" Signal Corps, U.S.A.

(1) - "Vacuum Tubes in Wireless Communication" Bucher [page 48]

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The "rectified" current in the plate circuit referred to above is of radio frequency and is therefore not heard in the telephone, the latter instrument indicating only the rectified current flowing from plate to filament. The regenerated radio frequency current is utilized, however, in the regenerative and amplification circuits to be discussed later.

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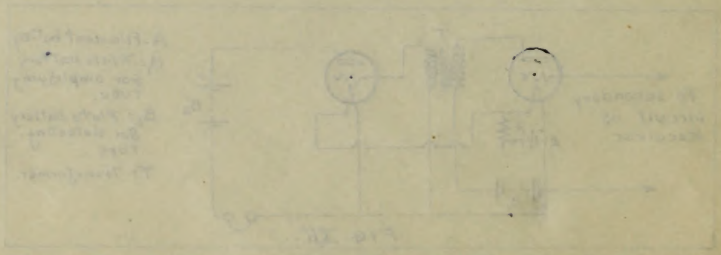


The primary of a transformer is generally connected in the plate circuit of the first tube, and the secondary in the grid circuit of the second tube, for still greater efficiency. As can be seen from Fig. 12, the same "A" battery may be used for both tubes.

If further amplification is desirable, the alternating current from the secondary of the transformer (still at radio frequency) may be delivered to the input (grid) circuit of a second amplifying tube, and the output circuit this second tube (current also at radio frequency) connected to a third tube acting as a detector, or a crystal rectifier may be used in place of the third tube. An amplifier such as the above is said to have two stages of amplification.

An amplifier in which the signal is amplified before reaching the detector (as in Fig. 12) is called a radio-frequency amplifier. If it is desired the currents which are of audio frequency after passing through the second tube (Fig. 12) can be further amplified by one or more audio-frequency stages. If, in the circuit shown in Fig. 12, the positions of the detector tube and the amplifier tube were reversed the signals would be amplified at audio frequency, or, in other words, the signals would be amplified after being detected. ①

For audio-frequency amplification, iron core transformers are used. In radio frequency amplification the transformers are generally smaller and have air cores.

The amplifying process may be carried on through several steps. At present, the limit for practical reasons appears to be six tubes. As a rule, when as many as six tubes are used, the general practice is to use three tubes as radio frequency amplifiers, then the detector tube, and two tubes as audio frequency amplifiers.

When more than three stages of radio frequency amplification are used, troublesome effects caused by regeneration (to be discussed later) occur. When more than two steps of audio frequency amplification are used, we are liable to get "howling" noises in the output circuit, also due to regenerative effects.

It is only by the use of amplifiers of the type described above that it is possible to use coil antennas in receiving and radio compass work.

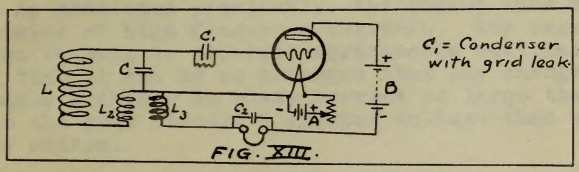
The use of even six tubes, however, requires very careful design to prevent difficulties caused by regenerative

① "The Principles Underlying Radio Communication" Signal Corps, U.S.A. [p. 481.]

effects. When a greater number of tubes is used, every disturbance is magnified. A six tube amplifier, designed properly, and utilizing combined audio and radio frequency amplification, will ordinarily give all the amplification desired.

REGENERATIVE AMPLIFICATION

By connecting a detector tube in the manner shown in Fig. 13, its sensitiveness may be enormously increased. This method multiplies the amplifying action of the tube, and was discovered by Armstrong.



C_1 = Condenser with grid leak.

From "The Principles Underlying Radio Communication." — Signal Corps, U.S.A.

FIG. XIII.

Oscillations in the circuit LL_2C (Fig. 13) applied to the grid, through condenser C_1, produce corresponding variations in the plate circuit, the continuous current in which is supplied by the plate "B" battery. This plate current flows through L3, and by mutual inductance, some of the energy of the plate oscillations is transferred back to the grid circuit, and the current in the circuit LL_2C is therefore increased. At the same time the regular detecting action is taking place in the tube. The condenser C_1 is charged in the usual way, but the charge which it accumulates is not proportional to the original signal strength, but to the final amplitude of the oscillations in the grid circuit. C_1 is provided with a "grid leak" shunted across it. The "grid leak" is a resistance of about a megohm, and serves to insure the leaking off of the charge accumulated in C_1 before the next wave train comes along and charges it again. The grid leak may also be connected directly across the grid and the filament of the tube.

Many modifications of the regenerative circuit shown in Fig. 13 are in use. Perhaps the simplest form of regenerative receiver is the one used in most of the radiophone sets at present being sold for public use under the Armstrong patent. These receivers are known as "single circuit regenerative" receivers, and operate with a single coil of wire and variable condenser for tuning purposes. Inside this coil is a "tickler", which is a coil of wire wound on a form, and connected in the plate circuit. By revolving this coil varying degrees of inductance may be obtained, thus controlling the regeneration. This outfit makes a very simple and efficient receiving set. It has one drawback, however, which government officials are

considering seriously at present. When oscillating, the tube in the single circuit arrangement acts as a generator of radio frequency currents, and may interfere to a greater or less extent with other receiving sets located in the same neighborhood.

At the present time the trend seems to be toward the development of radio frequency amplification, which has been rather neglected in the past owing to the greater amount of apparatus required, etc.

VACUUM TUBE AS A CONTINUOUS WAVE DETECTOR

As mentioned previously, the vacuum tube may act as a generator of high frequency currents. Any regenerative circuit can be made to generate spontaneous oscillations, providing that it can be so arranged that any change in grid voltage makes a change in plate current so large that there is induced in the grid circuit a greater voltage than was originally acting.

To receive signals from a sending station which is using the continuous wave system mentioned in the first part of this paper, some method of breaking the oscillations up into groups must be used, in order that they may be audible in the telephones. One method① utilizes a ticker or chopper which simply interrupts the circuits of the receiving tuner at a uniform rate per second (e.g. 300 to 600 times). Another method② uses the Goldschmidt tone wheel, which converts the incoming current of radio frequency into an audio frequency current.

A third method③ of receiving continuous waves employs the vacuum tube as an oscillator at radio frequencies, thus producing the "heterodyne" effect which arises from the interaction of two radio frequency currents in the aerial of the receiver, and results in the production of an audio frequency current in the telephone. An analogous case is furnished by the resultant sound wave coming from two tuning forks which are vibrating at slightly different frequencies. The sound which is heard alternately increases and decreases in loudness, giving the phenomenon known as "beats". The number of beats per second is equal to the difference in frequencies of the two forks. Thus, if two forks have frequencies of 230 and 225 vibrations per seond they combine to give a sound which beats five times per second.

Similarly, if two sources of undamped electrical oscillations of constant amplitude act on a circuit simultaneously, one of frequency, say, 80,000 cycles per second, and the other of 82,000 cycles per second, the amplitude of the

① ② + ③ - "Vacuum Tubes in Wireless Communication" - Bucher. [page 83.]

considerable serious at present. When oscillating, the tube in the simple circuit arrangement acts as a generator of radio frequency currents, and may interfere to a greater or less extent with other receiving sets located in the same neighborhood.

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Similarly, if two sources of undamped electrical oscillations of constant amplitude act on a circuit simultaneously, one of frequency, say, 80,000 cycles per second, and the other of 82,000 cycles per second, the amplitude of the

resultant oscillation will rise to a maximum 2,000 times per seond. One of these sources of undamped oscillations is of course the sending station, and the other may be a vacuum tube at the receiver, acting as a generator of radio frequency currents. This is called "beat" or "heterodyne" reception. When rectified by a crystal detector or vacuum tube the above would produce an audible note of frequency 2,000 in the telephone.

The principle is shown in Fig. 14.

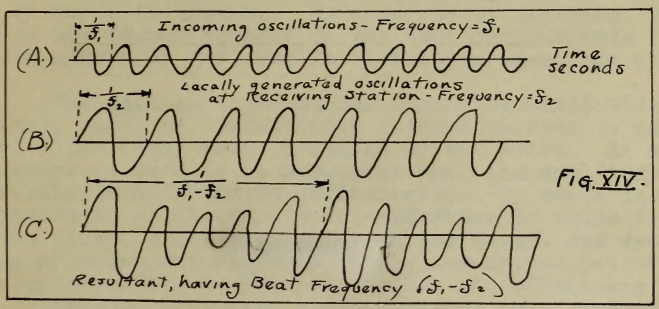


Fig. XIV.

From: "The Principles Underlying Radio Communication" — Signal Corps, U.S.A.

Oscillations of frequency f, are superimposed on oscillations of frequency f2. The resultant oscillations have a beat frequency of f1–f2, or, in other words, the maximum value of the resultant oscillations is attained f1-f2 times per second.

When this resultant wave form (C-Fig.14) is impressed upon any form of rectifying detector, most of the part of the wave below the zero axis is eliminated, as has already been explained. Thus the telephone diaphragm emits a tone corresponding to the beat frequency f1–f2. This rectifying detector may be the same vacuum tube which is used to generate the local oscillations if we use a regenerative circuit similar to that described in Fig. 13. That is, one tube may be used as a detector and generator of local oscillations at the same time.

This is called "autodyne" reception. The antenna circuit is tuned to the incoming signals, and then the local oscillation circuit is adjusted so that it is slightly out of tune with the signals. Beats of an audible frequency are produced. This is extremely sensitive to weak signals. circuit.

The heterodyne method, however, requires very sharp tuning adjustments[1] and is best adapted to long waves, such

[1]- "Vacuum Tubes in Wireless Communication" - Buchor. [page 91.]

those used by high power stations transmitting messages over long distances. The heterodyne method is also not well adapted to receiving damped waves or modulated continuous waves, such as are used in radio telephony, because the incoming waves have a number of frequencies instead of a single frequency.

THE OSCILLATION VALVE IN RADIO TELEPHONY

The principles of radio telephony are the same as those of radio telegraphy. More difficult problems, however, arise in the former because of the very complex wave form which is caused by the complex vibrations composing speech.

The problem is to design apparatus which will most accurately vary the transmitting antenna current in accordance with the sound waves produced by the voice. An alternating current is said to be modulated when the amplitude of its oscillations is varied periodically. In radio telephony the production of speech - modulated waves of radio frequency involves first, a generator of undamped waves, and secondly, a means of causing variations in the current output of the generator which will accurately follow the vibrations of the voice. The generator used must produce a pure, undamped wave. The two forms of generators in most general use are the high-frequency alternator and the vacuum tube. A speech-controlled variable resistance, such as the microphone, may then be inserted into the antenna circuit at the transmitting station, thus modulating the waves emitted, or better, may be placed in the D. C. power supply of the generating system in such a way as to vary the D. C. input, and hence the radio frequency output of the generating system.

When an electron tube is used as the generator, the simplest method of modulation is to insert the secondary of a transformer into a microphone circuit, as in Fig. 15.

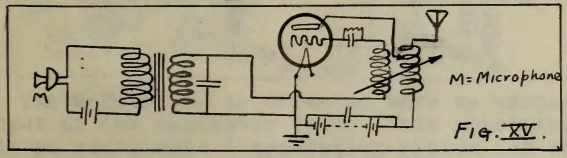
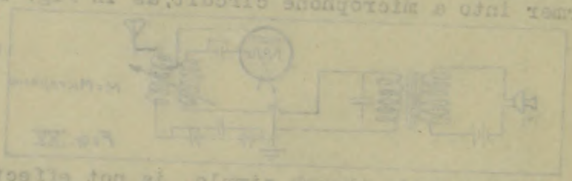


Fig. XV.

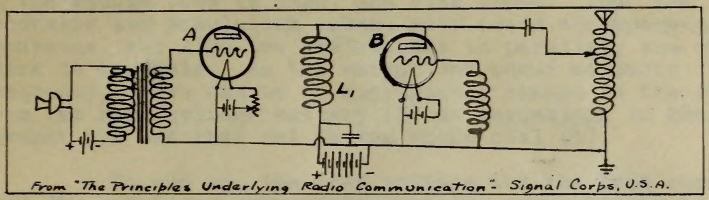
From "The Principles Underlying Radio Communication." Signal Corps, U.S.A.

This method, though simple, is not effective.[1] If two tubes instead of one are used, modulation can be effected easily by the so called "absorbtion method". The tube used as a generator of radio frequency oscillations is shunted by a second tube which acts as an absorber. The extent of the absorbtion varies at audio frequencies in accordance with

[1] "The Principles Underlying Radio Communication" Signal Corps, U.S.A. [page 579]



the wave form of the speech impressed upon the microphone. Fig. 16 shows a circuit utilizing two tubes in this way.



The plate circuit of tube A is parallel with the plate circuit of the generator tube B. The same radio frequency voltage exists across the plate circuits of the absorber tube and the generator tube. Since there is no corresponding radio frequency voltage on the grid of the absorber tube A, the absorber tube consumes radio frequency power from the output of the generator tube. The amount of power absorbed by this tube is varied at speech frequency by varying the grid voltage of "A" by use of a microphone. The inductance L1 must be a choke-coil of high impedance to currents of radio frequency. This method, while simple, is not efficient.

"The most common method of tube modulation is the varying of the input plate power. The variations in antenna current are more nearly proportional to the variations in the microphone current in this system."① The above system, however, is not used much in practice, mostly because there is a large drop in voltage across the modulative or "absorbing" tube which must be compensated for.

Practically all radio telephone transmitters which are now in actual use, utilize the circuit shown in Fig. 17.

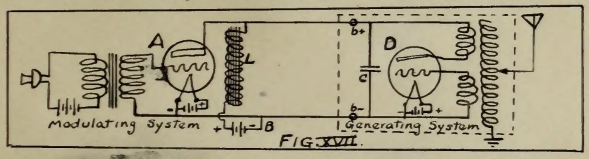
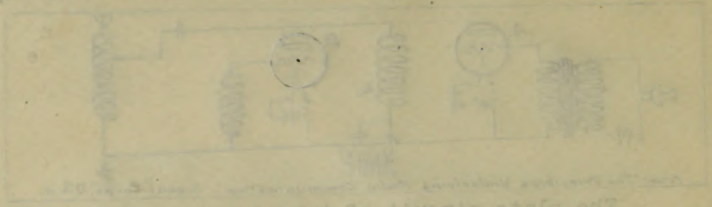


FIG. XVII.

From - "The Principles Underlying Radio Communication" - Signal Corps, U.S.A.

The modulation is effected here by variation of the power input of the generator tube. This apparatus inside the dotted lines represents a generating system for which power would ordinarily be supplied to the plate by connecting a high voltage batterv across the terminals marked b+ and b-. The condencer C acts as a by-pass for radio frequency current. It is necessary in any tube generating circuit to have only direct current flow in the plate circuit. The microphone in the grid circuit of the modulator tube (A) varies the grid voltage. When the grid voltage is low, the resistance

① "The Principles Underlying Radio Communication" Signal Corps, U.S.A. [page 521]



of the vacuum tube is high, and vice versa. Thus the generator and modulation tubes, with their accompanying apparatus, act like two resistances in parallel, one of which is variable. As the variations occur at audio frequency, there can be no appreciable change in the current from the high voltage battery (B) as variations in the current are smoothed out in the choke coil (L).

To sum up, the load voltage and the load current from the modulator tube constitute the power supply to a generating system, which has the characteristic that the antenna current is approximately directly proportional to the supply voltage. Thus the radio frequency output of the generator tube is modulated at speech frequency, and the variation in the wave emitted causes an audio frequency tone in the receiving equipment corresponding to the tone impressed upon the microphone of the transmitter. Many complicated circuits based upon that in Fig. 17 are used in radio telephone transmitting. For example some sets amplify the microphone power before the audio frequency is impressed on the grid of the modulator tube.

Reflecting upon some of the uses and applications of the oscillation valve referred to in this paper, it well deserves the name "the electrical acrobat", which it has been called. The valve is still in the process of development. Work is being done on it at present to reduce its filament current consumption and necessary plate voltage among other things. The future advance of the art of radio telegraphy and telephony will depend to a great extent on the further improvement of the vacuum tube.

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